Crash Test Between a 6-KG/M U-Channel Sign Support and a 1997 Geo Metro: FOIL Test Number 99F007

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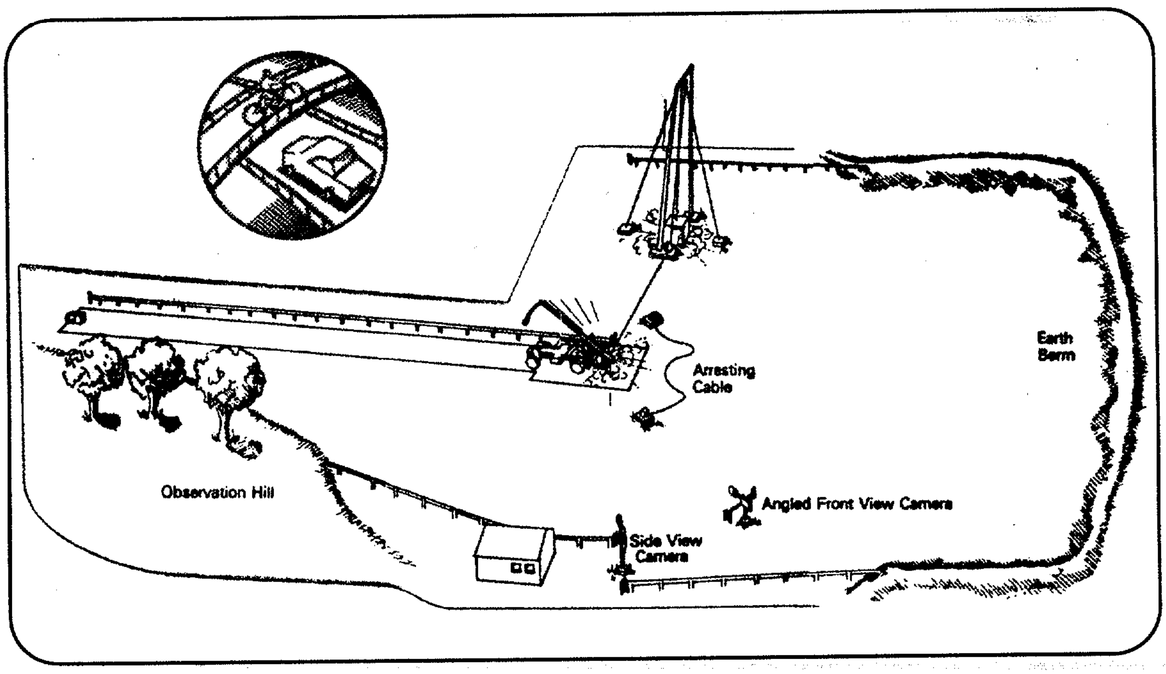

FOIL

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

ORIGINAL

FOREWORD

This report documents the results from one crash test between a 1997 Geo Metro two-door hatchback and a single-leg 6-kg/m u-channel sign support. The Federal Highway Administration (FHWA) has invested many resources in the development of finite element models (FEM) of passenger vehicles, pickup trucks, and roadside safety hardware. Computer simulations using these FEMs of collisions between the vehicles and roadside safety hardware are used to investigate the behavior of and improve the safety performance of roadside safety hardware. An essential step for developing the FEM is to validate the model by comparing data from simulation output with data collected from full-scale vehicle crash tests with roadside safety hardware. The FHWA's Federal Outdoor Impact Laboratory (FOIL) was used to conduct this test to develop and validate an FEM of the Geo Metro. The nominal test speed for the test was 100 km/h and the nominal test weight of the test vehicle was 820 kg.

This report (FHWA-RD-01-049) contains test data, photographs taken with high-speed film, and a summary of the test results.

This report will be of interest to all State departments of transportation; FHWA headquarters; region and division personnel; and highway safety researchers interested in the crashworthiness of roadside safety hardware.

Michael F. Trentacoste

Michael Trentacoste, Director
Office of Safety and Traffic
Operations Research and Development

NOTICE

Technical Report Documentation Page

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16. Abstract

This report contains the test procedures followed and test results from one crash test between a 1997 Geo Metro and a single-leg small sign support. The test was conducted at the Federal Highway Administration's (FHWA) Federal Outdoor Impact Laboratory (FOIL) located at the Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia. The target test speed for the test was 100 km/h and the target test inertial weight was 820 kg. A dummy was not used in this crash test. The test was conducted to provide data for validating a finite element model (FEM) of a Geo Metro and to investigate the potential for windshield penetration by the sign support after fracture. Computer simulations using the latest FEM of a Geo Metro indicated that windshield penetration was possible while striking a small sign support with a sign panel mounting height of 1,525 mm. The test results were unable to verify the simulation's prediction that if a Geo Metro struck this particular sign support design there was a high probability of windshield penetration or severe windshield/roof damage. This result may have occurred because the material properties of the FEM sign post did not match those of the actual sign post. Because the post did not fracture, other important safety performance measures including predictability of device activation and longitudinal occupant impact velocity, did not meet the safety performance criteria specified in the National Cooperative Highway Research Program (NCHRP) *Report 350*, test designation 3-61. The data and high-speed film coverage will aid in the continuing evolution of the Geo Metro FEM.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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SCOPE

This report documents the procedures followed and the results from one crash test conducted at the Federal Outdoor Impact Laboratory (FOIL) located at the Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia. The test involved a 1997 Geo Metro two-door hatchback traveling at 100 km/h and a single-leg 6-kg/m sign support mounted in a strong soil. The test was conducted to provide actual crash test data for verifying the results from finite element computer simulations investigating variation in sign support safety performance as a function of sign mounting height. The simulation efforts were conducted by the National Crash Analysis Center (NCAC).

The results indicate that, for this particular sign post and vehicle combination, a mounting height of 1.5 m did not lead to windshield contact by the sign panel during a collision. However, the results further indicate that the calculated safety performance values were above the allowable safety performance criteria for sign supports outlined in the National Cooperative Highway Research Program Report 350 (*NCHRP Report 350*).[1]

TEST MATRIX

One crash test was performed on a 6-kg/m sign support. The test was conducted in accordance with *NCHRP Report 350* test designation 3-61. Test designation 3-61 outlines parameters for a safety performance test of support structures involving an 820C (820-kg) vehicle striking a support at 100 km/h with an impact angle of 0° to 20°. Table 1 summarizes the nominal test conditions for test 99F007. The target impact location was center-of-post aligned with the vehicle's longitudinal centerline.

Table 1. Summary of nominal test conditions.

Test number	99F007
Test date	09-14-99
Vehicle	1997 Geo Metro
Nominal vehicle weight	820 kg
Nominal speed	100 km/h
Impact angle	0°
Support	6 kg/m u-channel (hat-section)
Soil	FOIL strong soil pit, Virginia 21A
Embedment depth	1,220 mm
Impact location	Vehicle centerline

VEHICLE

The test vehicle used was a 1997 Geo Metro LSi two-door hatchback with an automatic transmission. Prior to the test, the vehicle was drained of all fluids and its curb weight recorded. The vehicle's inertial properties were then measured using the FOIL inertial measurement device (IMD). The vehicle was stripped of certain components (spare tire, rear seat, shifter linkage, etc.) and instrumented with data acquisition equipment, sensors, an automated brake system, a high-speed film camera, and vehicle guidance equipment. The final vehicle test weight was determined and the vehicle's inertial properties were measured a second time as instrumented. The target vehicle inertial weight was 820 kg. A dummy was not used for this test. No components were removed from the vehicle's engine compartment. The battery remained in a charged state and connected to the power harness. The key was placed in the "start" position to activate air-bag power. Table 2 summarizes the test vehicle's inertial properties and figure 1 lists the vehicle's physical parameters.

Table 2. Inertial properties of 1997 Geo Metro.

Test Number	Weight (kg)	Height (mm) *	Long.cg ** (mm)	Pitch kg•m^2	Roll kg•m^2	Yaw kg•m^2	Bumper Height (mm)	Wheel Base (mm)
Curb Weight Configuration								
99F007	815	535	844	1,008	244	1,108	455	2360
Test Configuration (inertial)								
99F007	835	525	842	1,027	255	1,098	455	2360

* Height of vehicle center-of-gravity.
** Longitudinal center-of-gravity, distance behind front axle.

DATE: 9-14-99 TEST NO: 99F007 TIRE PRESSURE: 35 psi MAKE: GEO

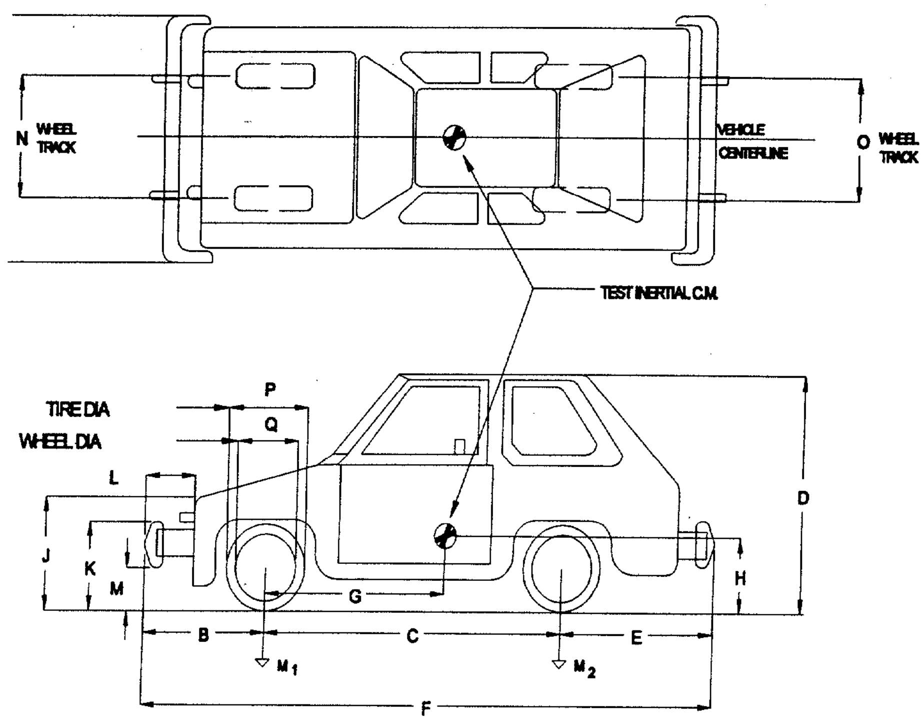
MODEL: METRO YEAR: 1997 ODOMETER: 37,807 GVW: ______

TIRE SIZE: 155/80 R13 VIN NUMBER: 2C1MR2299V6762950 TREAD TYPE: ______

MASS DISTRIBUTION:		LF	RF	LR	RR
CURB:		271	253	142	149
	TEST INERTIAL:	275	262	147	151

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

NONE



ENGINE TYPE: 1.3L 4 CYL.

ENGINE CID: ______

TRANSMISSION TYPE:

X AUTO

___ MANUAL

OPTIONAL EQUIPMENT:

AIR CONDITIONING

Radio

Driver and passenger

Air Bags

DUMMY DATA:

TYPE: None

MASS: ______

SEAT POSITION: ______

GEOMETRY

A	1525	E	591	J	718	N	1385	R	
B	830	F	3785	K	502	O	1351	S	
C	2363	G	840	L	106	P	577	T	
D	1415	H	525	M	410	Q	361	U	

MASS	CURB	TEST INERTIAL	GROSS STATIC
M_1	524	537	537
M_2	291	298	298
M_T	815	835	835

1 psi = 6.89 kPa

Figure 1. Vehicle properties for test 99F007.

TEST DEVICE

The device tested at the FOIL was a single-leg small sign support buried in *NCHRP Report 350* S1 strong soil. The sign support was constructed from one 6-kg/m u-channel hat-section and a 650-mm square aluminum sheet. The u-channel was cut to length (3,660 mm)and the sign panel was attached 1,525 mm above the ground line. The assembled sign support was placed in a 1,220-mm hole within the FOIL strong soil (crush-and-run) pit. The hole was back filled and compacted in 305-mm increments until ground level was reached. The sign panel was attached to the sign post using two 9-mm hardware quality bolts. A flat round washer was placed under the bolt head and nut.

Figure 2 illustrates the sign support installation. Refer to figures 7 and 8 in Appendix A for photographs of the test installation. Appendix C contains a stress-strain curve for the sign post material. The material testing was performed on specimens taken from the actual sign post tested. The material testing was conducted by the NCAC.

INSTRUMENTATION

Speed-trap, accelerometer, and high-speed film data were collected during the sign support test.

Speed trap. A speed trap was used to determine the vehicle's speed just prior to contact with the sign support. The center of the speed trap was located approximately 4 m before the sign support. The speed trap consisted of a set of five contact switches fastened to the runway in 305-mm intervals. As the vehicle passed over the switches, electronic pulses were recorded on analog tape.

Transducer data. The instrumentation used during the test consisted of a tri-axial accelerometer and a tri-axial angular rate transducer at the vehicle's center-of-gravity (c.g.). The data from the transducers were recorded by two data acquisition systems: the Diversified Technical Systems TDAS PRO onboard data acquisition system (TDAS PRO) and an umbilical cable tape recorder system. Table 3 describes the instrumentation used during the test. A three-dimensional sensor location is included in table 3. The location coordinates were referenced from the right-front wheel hub, which was 265 mm above ground.

The TDAS PRO is a self-contained system. The output from the sensors was filtered, digitally sampled, and digitally stored within the TDAS 8-channel modules mounted directly to the test vehicle inside the occupant compartment. The TDAS PRO system was set with a 3000-Hz analog pre filter and a digital sampling rate of 12,500 Hz. C.g. acceleration data, windshield data, and rate transducer data were collected via the TDAS PRO system.

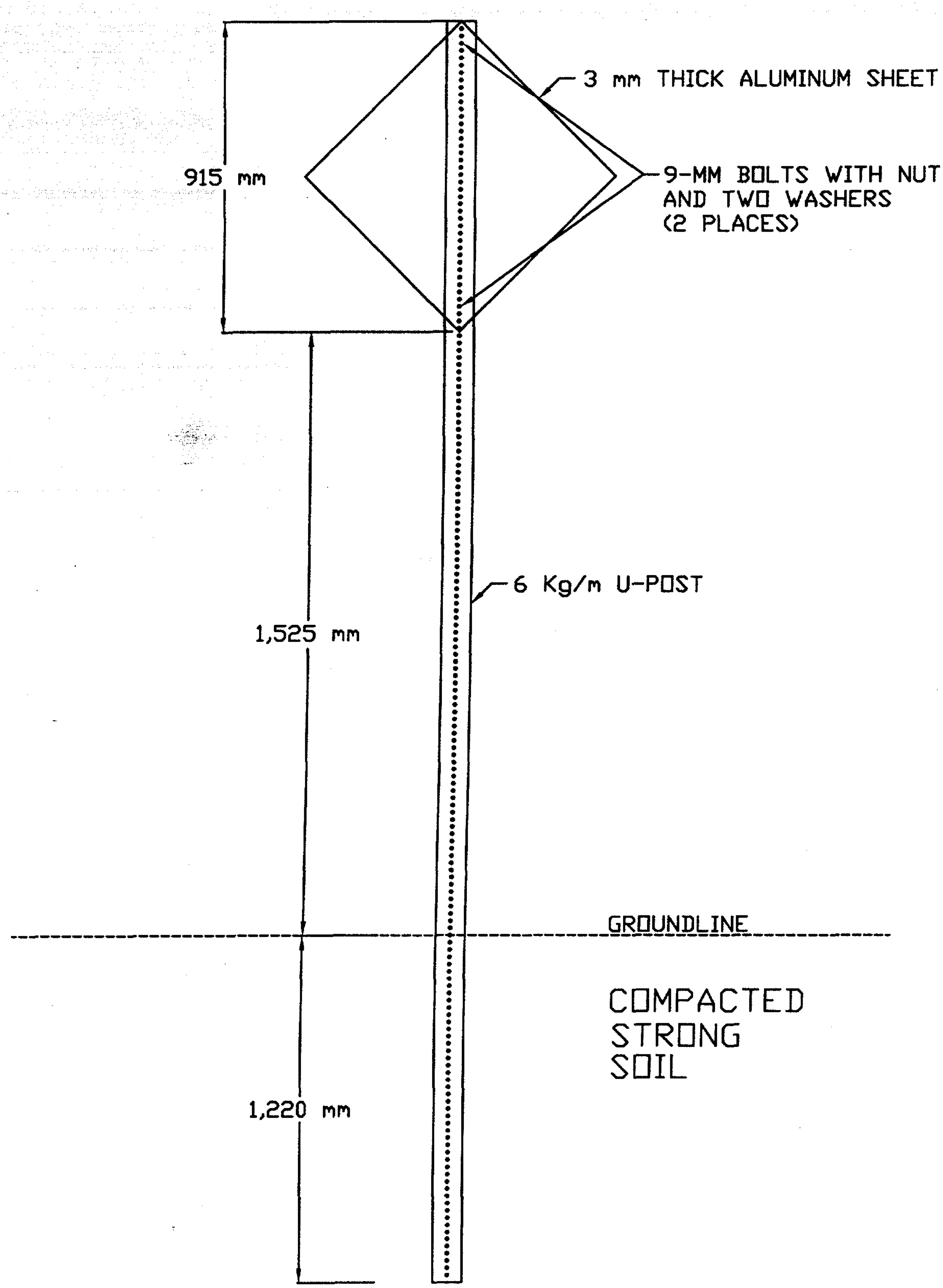


Figure 2. Sketch of small sign support.

The FOIL umbilical cable system utilizes a 90-m cable between the vehicle transducers and a rack of signal conditioning amplifiers. The output from the amplifiers was recorded on 25-mm magnetic tape via a Honeywell 5600E tape recorder. After the test, the tape is played back through anti-aliasing filters (set to 3000 Hz), then input to a Data Translation analog-to-digital converter (ADC). The sample rate was set to 12,500 Hz. The umbilical cable system recorded c.g. acceleration data.

Table 3. Summary of instrumentation and channel assignments for test 99F007.

Ch	Transducer	Maximum range	Data description	Location* (X,Y,Z) mm
TDAS PRO onboard data system				
1	Accelerometer	100 g	Vehicle c.g., X-axis	-800,750,140
2	Accelerometer	100 g	Vehicle c.g., Y-axis	-800,750,140
3	Accelerometer	100 g	Vehicle c.g., Z-axis	-800,750,140
4	Accelerometer	200 g	Roof-windshield	-930,725,1,025
5	Rate transducer	500 °/s	Pitch rate, c.g.	-800,750,140
6	Rate transducer	500 °/s	Roll rate, c.g.	-800,750,140
7	Rate transducer	500 °/s	Yaw rate, c.g.	-800,750,140
Umbilical cable, tape recorder system.				
1	Accelerometer	100 g	Vehicle c.g., X-axis	-800,750,140
2	Accelerometer	100 g	Vehicle c.g., Y-axis	-800,750,140
3	Accelerometer	100 g	Vehicle c.g., Z-axis	-800,750,140
11	Contact switch	1.5 V	Time of impact, T0	Not available
12	Contact switches	1.5 V	Runway speed trap	Not available
14	Generator	1.5 V	1 kHz reference signal	Not available

* Origin located at right front wheel hub (265 mm above ground)

High-speed photography. The crash test was photographed using seven high-speed cameras with an operating speed of 500 frames/s. All high-speed cameras used Kodak 2253 daylight film. In addition to the high-speed cameras, one real-time camera loaded with Kodak 7239 daylight film and two 35-mm still cameras were used to document the test. Table 4 summarizes the cameras used and their respective placements. The camera numbers listed in table 4 are shown in figure 3.

Table 4. Summary of camera placement.

Camera number	Type	Film speed frames/s	Lens (mm)	Location
1	LOCAM II	500	10	Overhead
2	LOCAM II	500	5.7	On-board, in vehicle
3	LOCAM II	500	50	Right side 90° to impact
4	LOCAM II	500	100	Right side 90° to impact
5	LOCAM II	500	25	Right side 45°
6	LOCAM II	500	150	Behind sign support in line with vehicle
7	LOCAM II	500	100	Left side 45°
8	BOLEX	24	ZOOM	Documentary
9	CANNON A-1	still	ZOOM	Documentary
10	CANNON A-1	still	ZOOM	Documentary

DATA ANALYSIS

Data were collected via the FOIL analog tape recorder system, including speed-trap data, the FOIL TDAS PRO onboard data system, and high-speed film.

Speed trap. As the vehicle passed over the speed-trap tape switches, electronic pulses were recorded to analog tape. The tape was played back through a Data Translation ADC inside a desktop computer. The time between pulses was then determined using the software provided with the ADC. The time intervals between the first pulse and each of the subsequent four pulses together with the distances between corresponding tape switches were entered into a computer spreadsheet and a linear regression was performed to determine the best-line fit of the data points. The impact velocity was then determined from the slope of the best-line fit of the displacement vs. time curve.

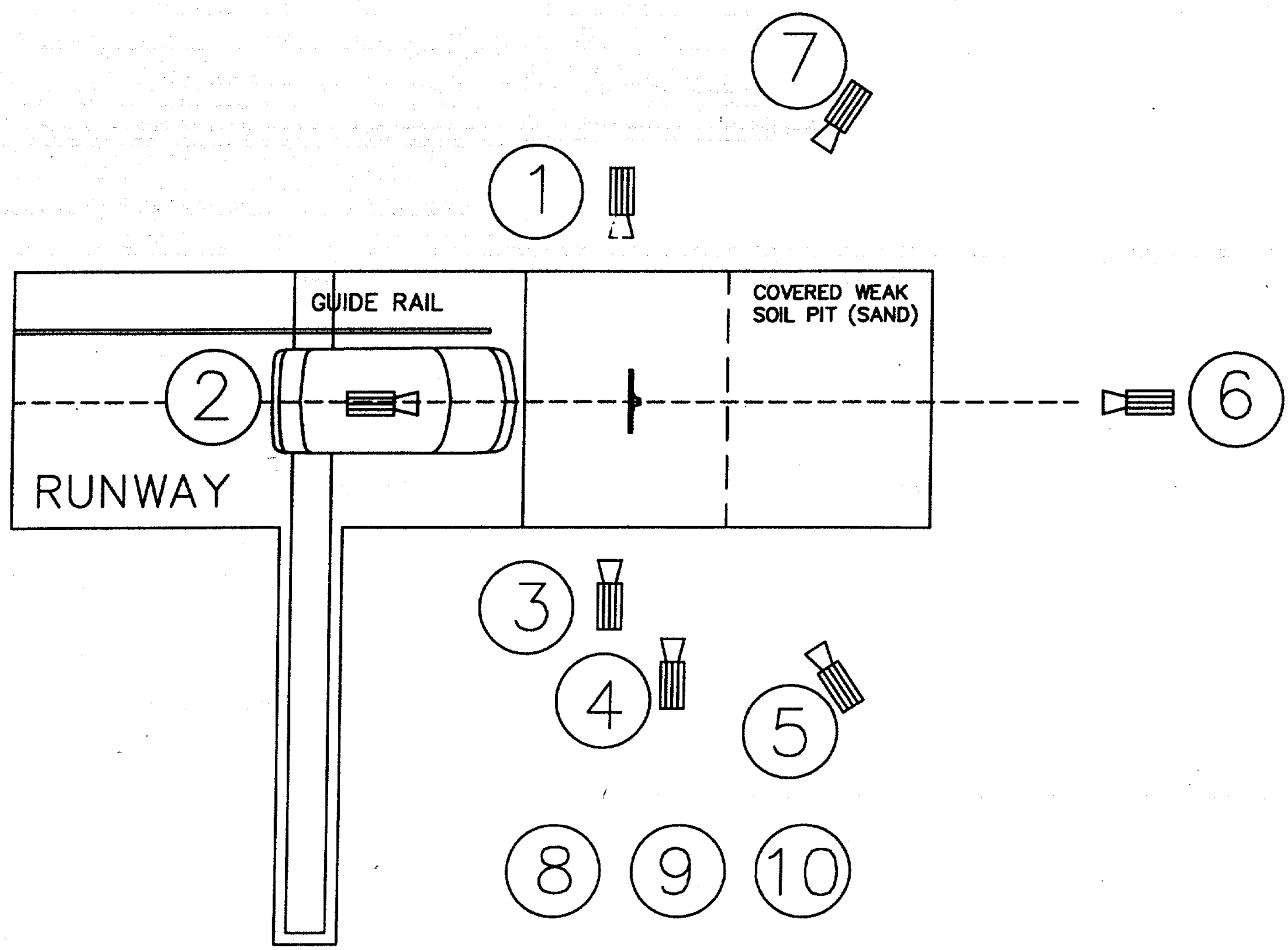


Figure 3. Camera placement, test 99F007.

Transducer data package. After the test, data from both data systems were converted to digital format and stored. The digital data from the tape recorder system and the TDAS PRO system were converted to the ASCII format, the zero bias was removed, and the data were digitally filtered using a digital Butterworth low-pass filter. The data from the crash test were digitally filtered with a cutoff frequency of 300 Hz (SAE J211 Class 180). The data were transferred to a spreadsheet for analysis.

The longitudinal c.g. acceleration data were integrated twice to produce velocity and displacement traces. Using techniques outlined in *NCHRP Report 350* the occupant risk values were determined.

High-speed photography. The crash event was recorded on 16-mm film by seven high-speed cameras. The film from the camera perpendicular to the vehicle trajectory, with a 50-mm lens, was analyzed for initial vehicle velocity. The overhead camera was used to verify the impact location, impact angle, exit angle, and exit speed. Analysis was performed using an NAC Film Motion Analyzer model 160-F in conjunction with a desktop personal computer. The motion analyzer digitized the 16-mm film, reducing the image to Cartesian coordinates. The Cartesian coordinate data were then imported into a computer spreadsheet for analysis. Using the Cartesian coordinate data, a displacement vs. time history was obtained. A linear regression was performed on the first 20 data points of the displacement vs. time traces to verify the vehicle's impact velocity. The film was used to verify data obtained from the speed trap and rate transducer and could be used in the event of transducer malfunction. The film was used to observe roll, pitch, and yaw angular displacements. The speed trap and accelerometer data were the primary data systems.

RESULTS

The Geo Metro was positioned on the runway and attached to the FOIL propulsion system. The windows were up, the emergency brake was released, and the ignition was in the "on" position to activate the air-bags. The vehicle was accelerated to 99.0 km/h prior to striking the small sign support. The vehicle made first contact with the sign post 50 mm to the left of the vehicle centerline. The vehicle bumper began to collapse on contact with the sign support. At 0.010 s after contact the bumper had been pushed back to the radiator while the sign post was slightly bowed and had began to plow through the soil. The sign post and the plowing action imparted enough force on the vehicle to deploy the air-bags (0.034 s). The vehicle continued to flatten the sign post. By 0.050 s the sign panel had been drawn down to the vehicle's hood but the sign panel did not slap the hood or

windshield. The vehicle flattened the sign post and passed over the sign support by 0.102 s. The vehicle's bumper was torn from the vehicle as the sign post wrapped around the vehicle's front-end. The vehicle passed over the sign support continuing forward on its original trajectory into the FOIL run-out area where the brakes were applied. The vehicle remained stable and upright. The vehicle came to rest after contact with the FOIL catch fence 101 m downstream from the impact location. Figure 4 summarizes the results from the small sign support test. Appendix A contains photographs of the test during the collision and the pre- and post-test environments. Table 5 lists the maximum and minimum peak values obtained from the vehicle accelerometers. The values listed are Class 180 data (digital filter cut-off frequency of 300 Hz). Appendix B contains data plots of the data collected from each vehicle sensor and velocity and displacement data plots created from the longitudinal c.g. acceleration trace. All acceleration data plots are from Class 180 data.

Table 5. Maximum and minimum peak values recorded.

Location	**Peak Acceleration (g's)**	
	Max (+)	**Max (-)**
C.g. X-axis	15.8	33.2
C.g. X-axis, redundant	15.6	32.8
C.g. Y-axis	11.6	11.2
C.g. Y-axis, redundant	10.0	10.9
C.g. Z-axis	13.0	13.0
C.g. Z-axis, redundant	12.7	13.1
Windshield acceleration	88.2	57.7

<u>Occupant responses.</u> The longitudinal occupant impact velocity (OIV) was determined to be 5.2 m/s and occurred 0.172 s after initial contact between the vehicle and the sign support. The OIV value is above the limits specified in *NCHRP Report 350*. The longitudinal ridedown acceleration was below the allowable limits specified and was determined to be 1.1 g's.

<u>Vehicle damage.</u> Damage to the vehicle was extensive. The hood, grill, head lights, and core supports were either crushed and/or dislodged from the vehicle. The bumper and lower front cross-member were torn from the vehicle and remained next to the sign support. Both air-bags were deployed.

<u>Sign damage.</u> The sign support was bent and twisted and laid flat. The post did pull out of the soil. The u-channel web was torn vertically (approximately 460 mm). The sign post did not fracture or shear. The sign post could not be reused.

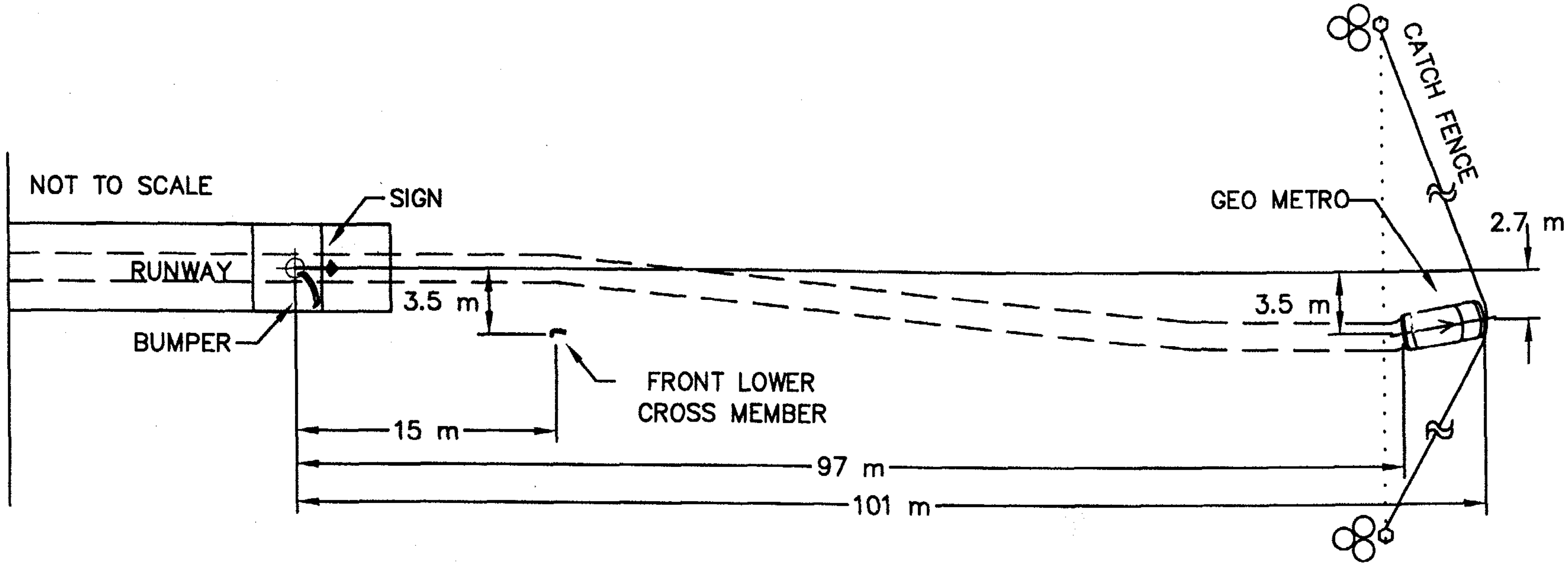
CONCLUSION

The data were successfully collected and the high-speed film successfully taken during the sign support test. The data and film will aid in the development and validation of a Geo Metro FEM and will help make sign mounting height recommendations. The film and sensor data did not reveal contact between the sign support and the vehicle's windshield. The sign post did not fracture as anticipated. This result may have occurred because the material properties of the FEM sign post did not match the material properties of the actual tested sign post (determined after the test). Because the sign post did not fracture, other safety performance measures were not acceptable.

The results summarized in figure 4 indicate that the 6-kg/m small sign support embedded in strong soil did not meet the safety performance criteria outlined in *NCHRP Report 350* (test designation 3-61). The sign support did not fracture as anticipated and the longitudinal OIV (5.2 m/s) was higher than the allowable limit (5.0 m/s). Table 6 summarizes the safety performance of the small sign support.

Table 6. Sign support safety performance summary.

Evaluation Factor	**Evaluation Criteria**	**Pass (P) or Fail (F)**
Structural Adequacy	**Test article should activate in a predictable manner.**	**F, fracture anticipated**
Occupant Risk	Occupant compartment intrusion, debris hazard.	P, none
	Vehicle should remain upright and stable.	P
	Longitudinal OIV (<5 m/s).	**F, 5.2 m/s**
	Longitudinal ridedown (<20 g's).	P, 1.1 g's
Vehicle Trajectory	Vehicle trajectory should not intrude into adjacent lanes.	P
	Vehicle trajectory behind article is acceptable.	P



Test location............................FHWA FOIL
Test number..................................99F007
Date...........................September 14, 1999
Test designation..............NCHRP 350 test 3-61
Test device.........................Sign support
  Posts..........Single leg 6-kg/m u-channel post
  Sign panel.........650-mm square aluminum sheet
  Soil.............Compacted 21A or crush-and-run
  Panel height.........................1,525 mm
  Total height above ground..............2,440 mm

Foundation........Embedded 1,220 mm in strong soil

Vehicle............................1997 Geo Metro
    Weight: Inertial.......................835 kg
            Gross..........................835 kg
            Dummy.......................No dummy
Impact speed..........................99.0 km/h
Actual impact location.......50 mm left of center
Impact angle...................................0.0°

Occupant Risk:	Observed	Design/Limit
Longitudinal:		
Occupant delta V at 0.6 m..........	5.2 m/s	3/5 m/s
Ridedown acceleration..............	1.1 g's	15/20 g's
Lateral:		
Occupant Delta V at 0.3 m..........	no contact	NA
Ridedown acceleration..............	no contact	NA

Peak 50 ms acceleration:
    Longitudinal.............................. 7.1 g's
    Lateral.............................. .....0.9 g's
Vehicle Damage:
    Traffic Accident Data (TAD)..................12-FC-4
    Vehicle Damage Index (VDI)...................12FCEN3
    Static crush.................................305 mm
Post fracture..................460 mm vertical tear in web

Exit speed.................................73.9 km/h
Exit angle.....................................0.0°

Figure 4. Summary of results, test 99F007.

APPENDIX A. TEST PHOTOGRAPHS 99F007

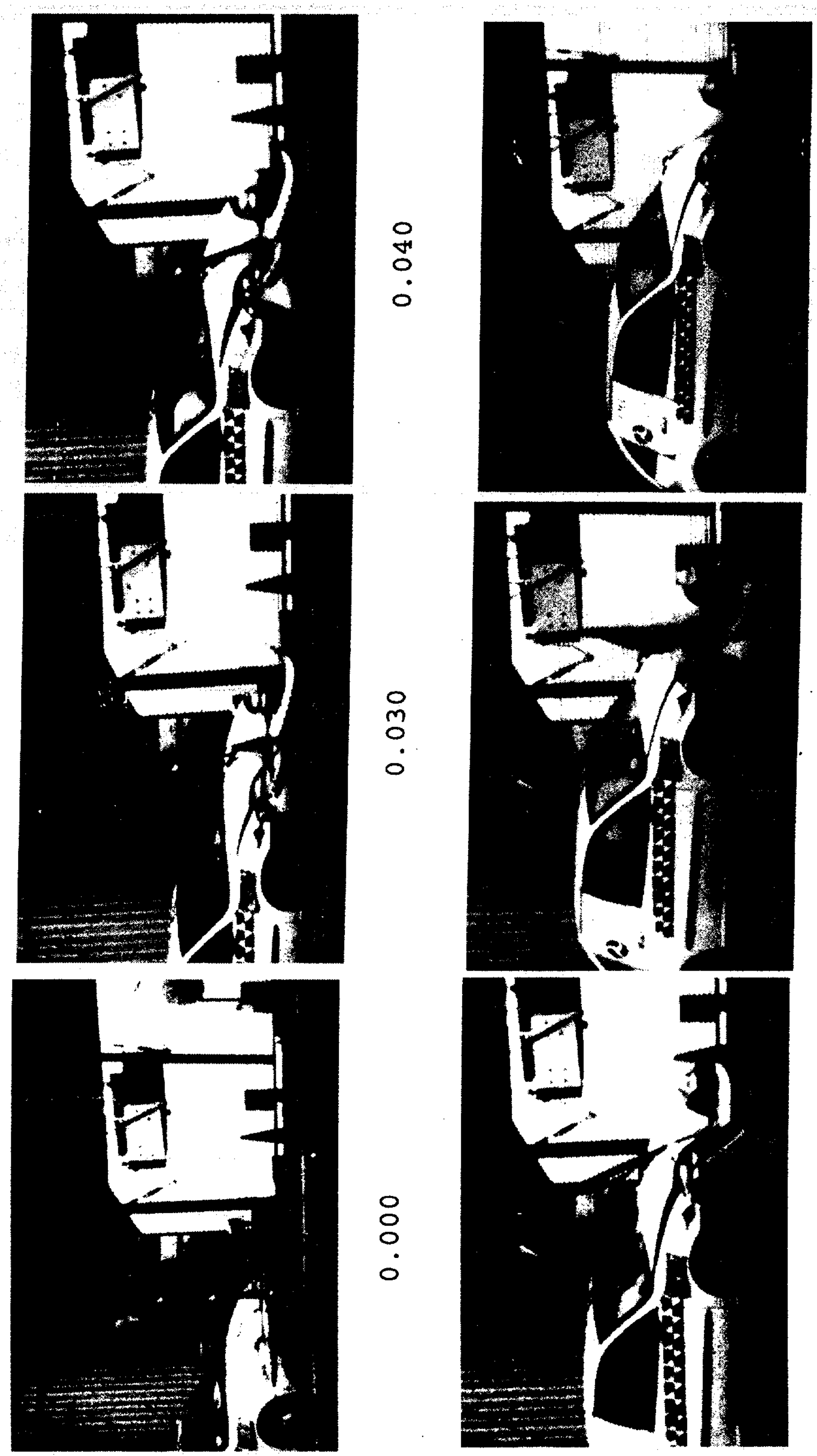
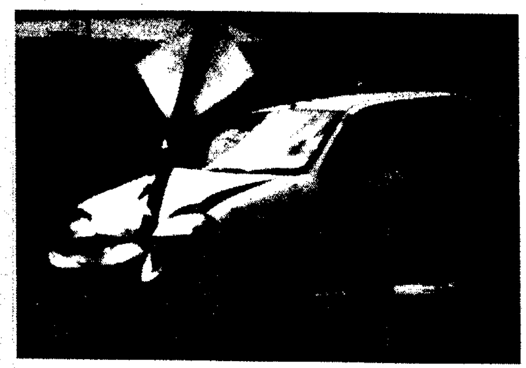


Figure 5. Test photographs during impact, test 99F007.

0.030



0.040

0.050

0.060

0.070

0.080

Figure 6. Test photographs during impact, test 99F007 (continued).

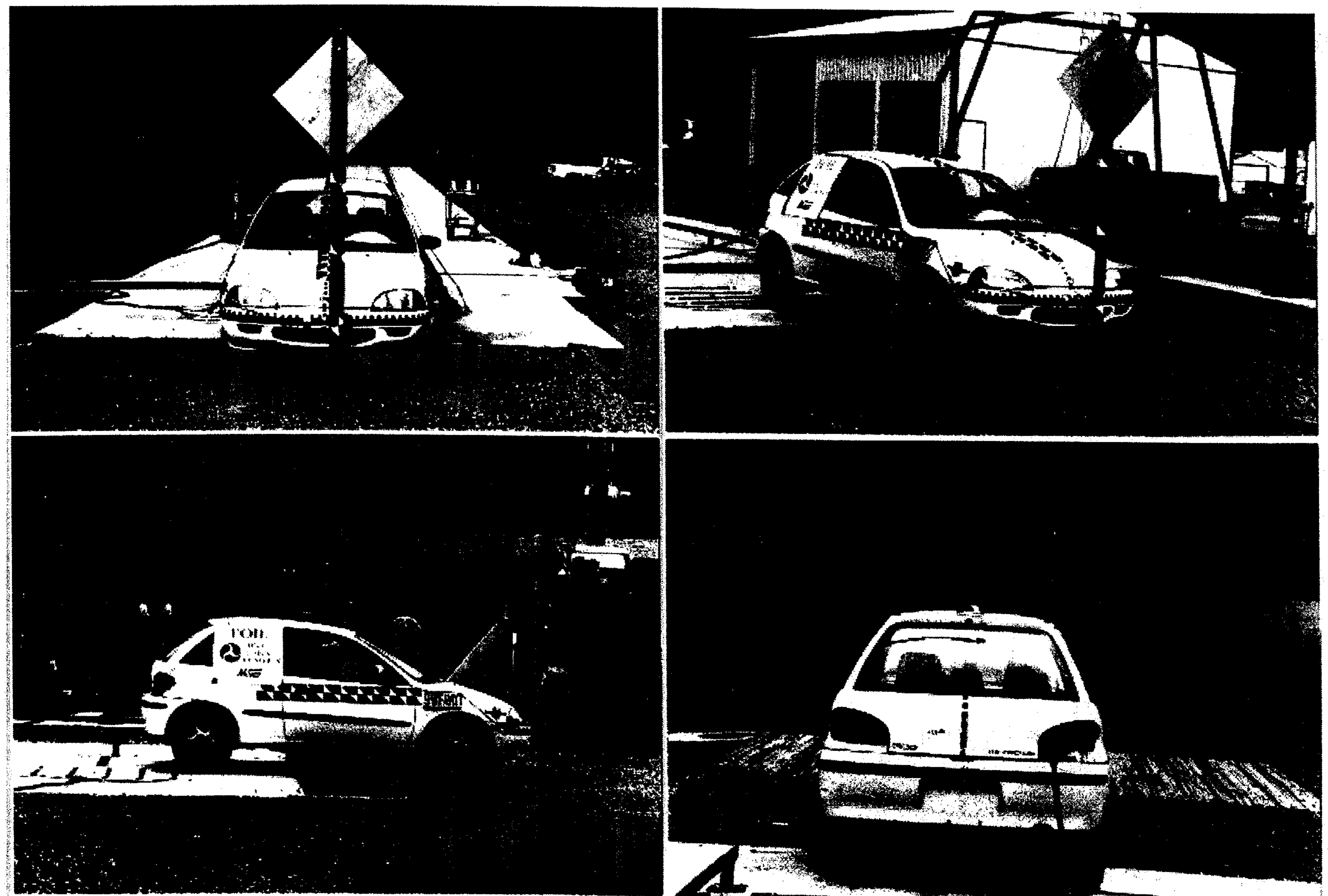


Figure 7. Pre-test photographs, test 99F007.

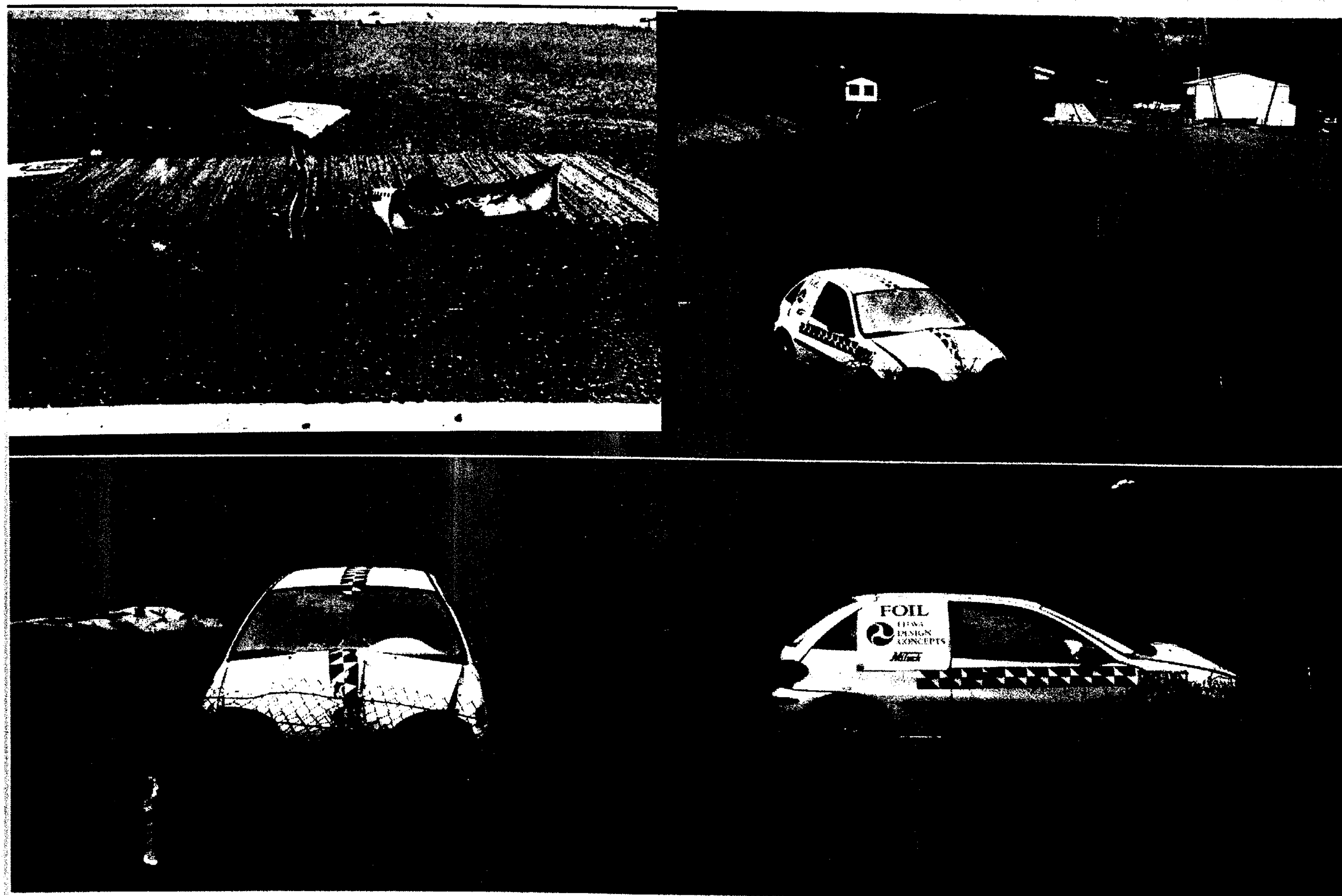


Figure 8. Post-test photographs, test 99F007.

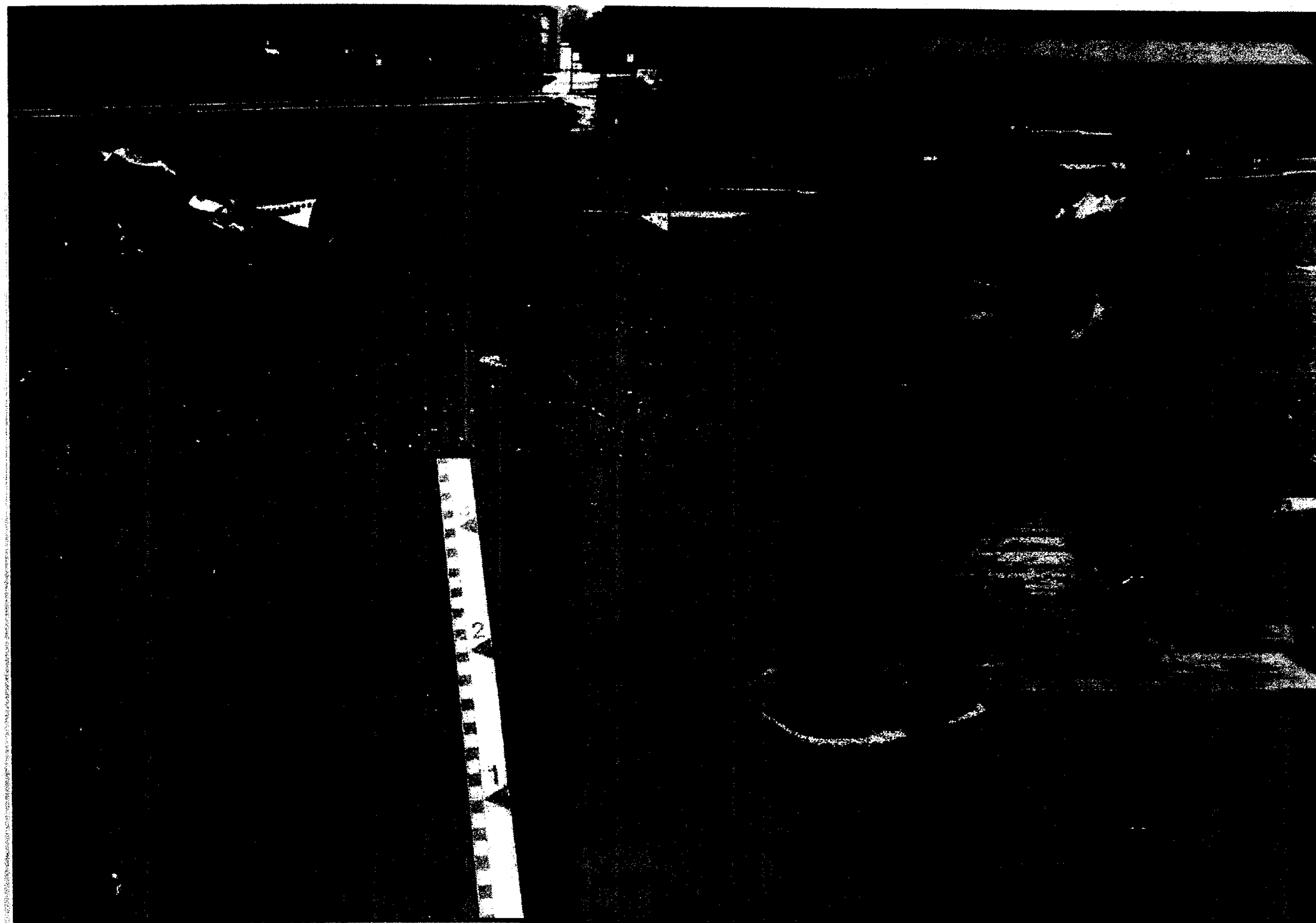


Figure 9. Post-test photographs continued, test 99F007.

Figure 10. Additional post-test photographs, test 99F007.

APPENDIX B. DATA PLOTS, TEST 99F007

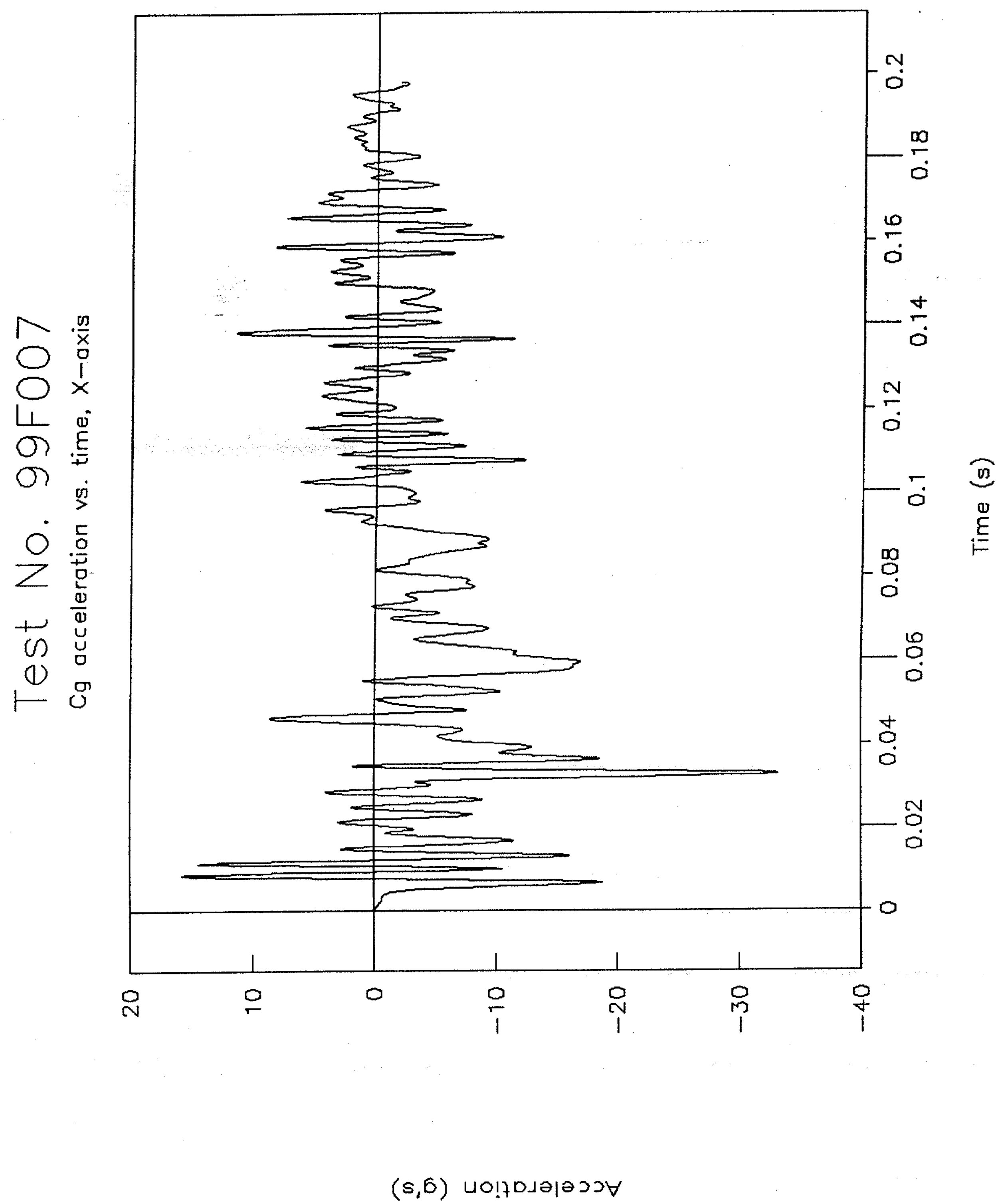


Figure 11. C.g. acceleration vs. time, X-axis, test 99F007.

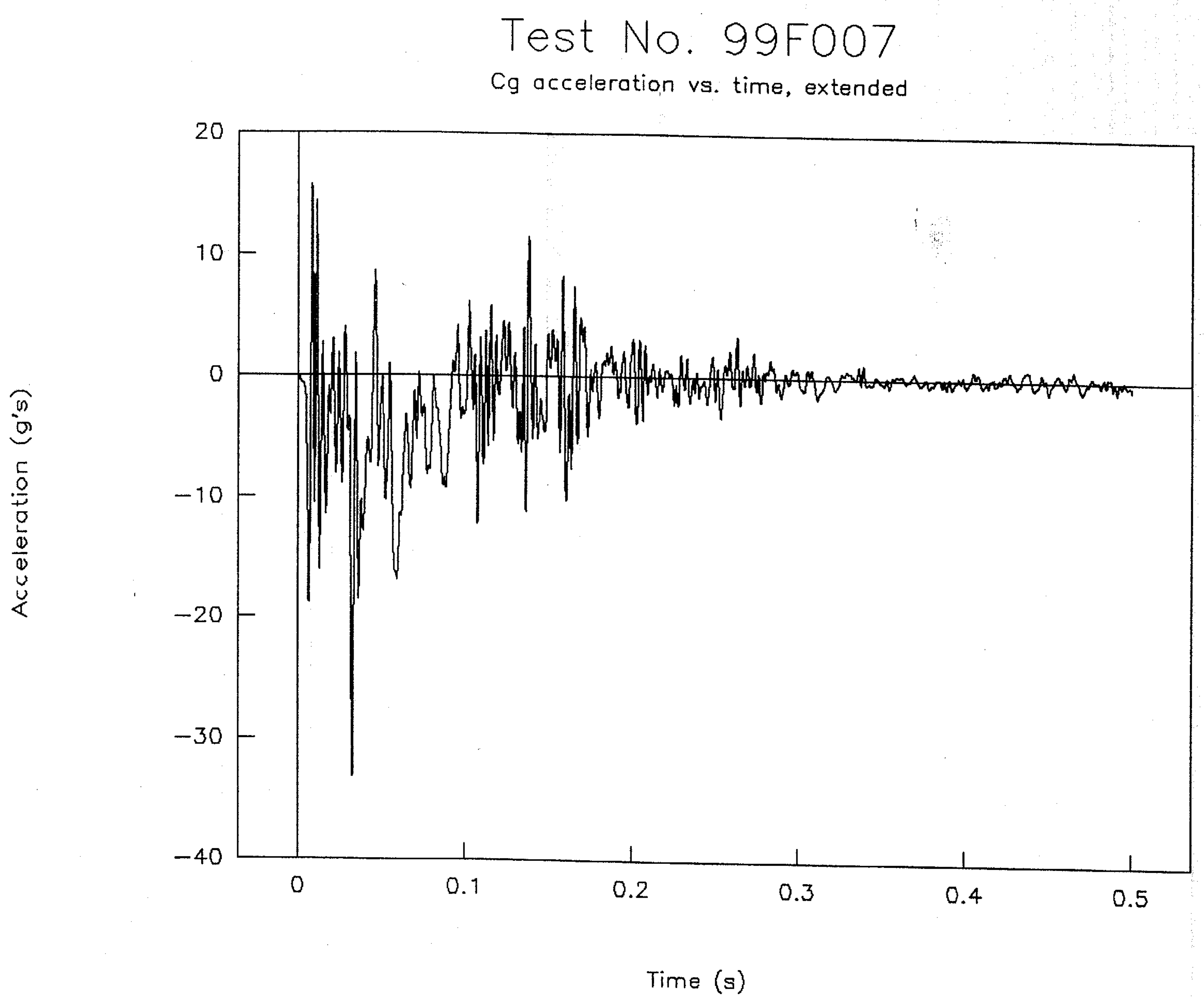


Figure 12. C.g. acceleration vs. time, X-axis extended, test 99F007.

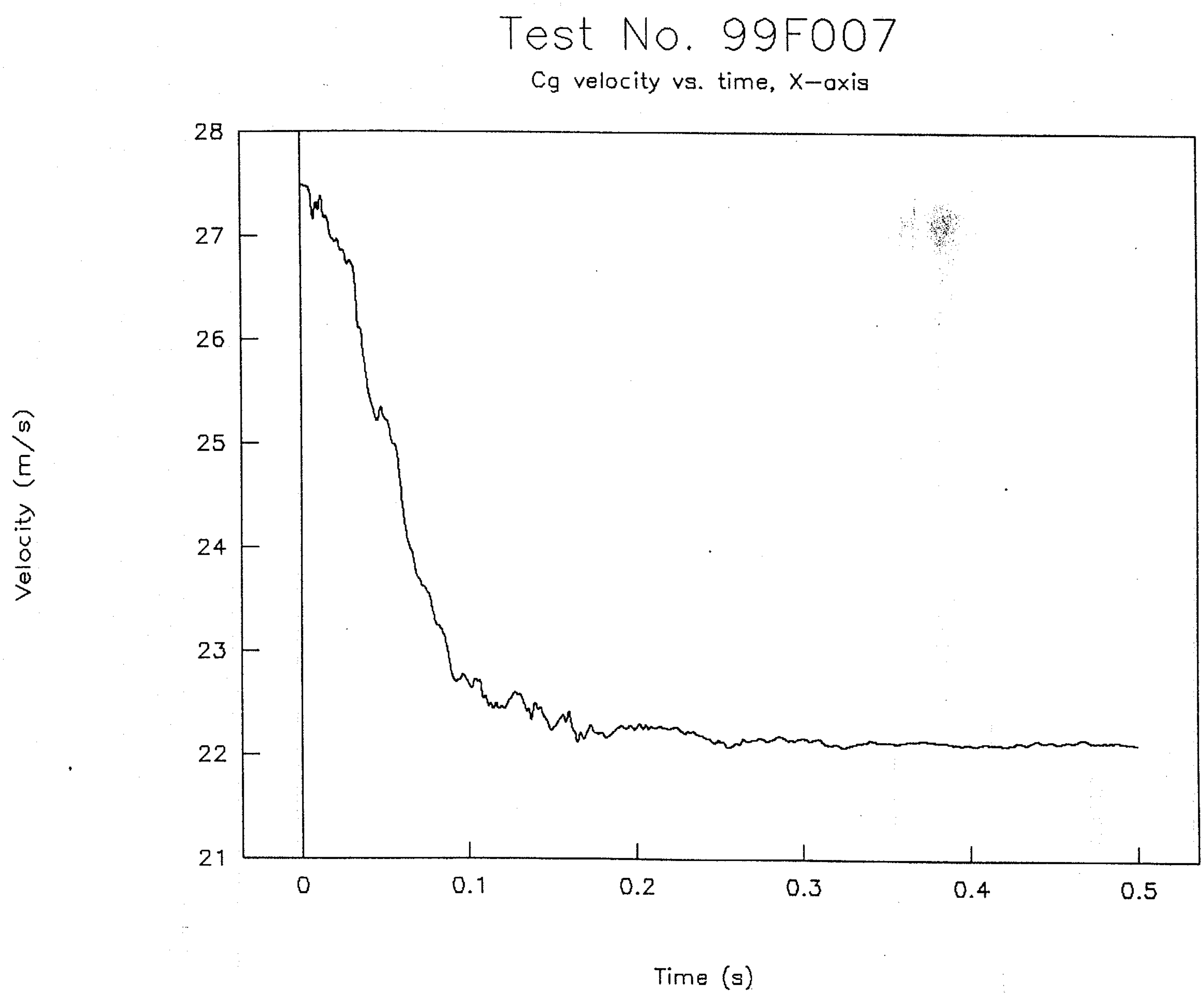


Figure 13. C.g. velocity vs. time, X-axis, test 99F007.

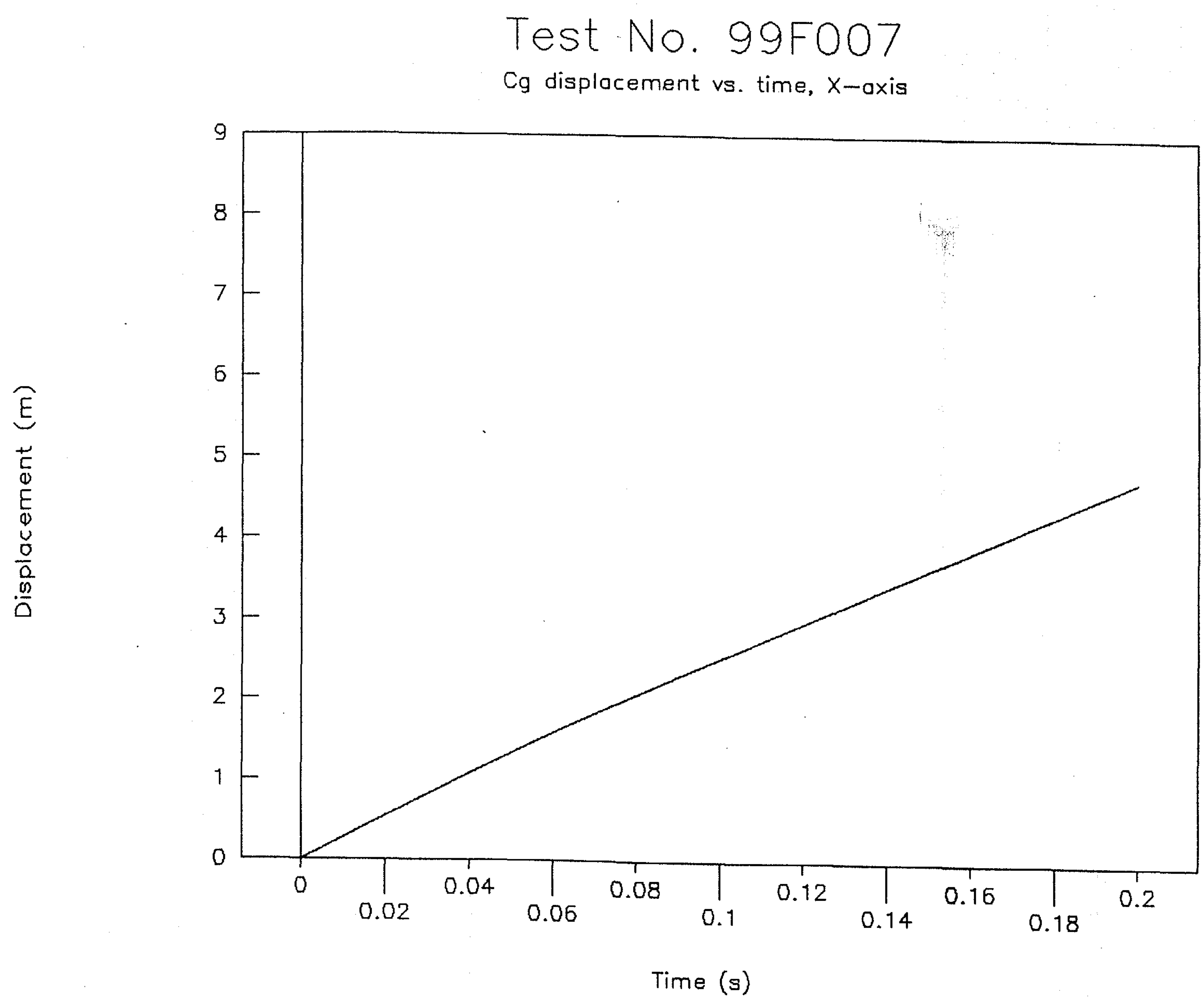


Figure 14. C.g. displacement vs. time, X-axis, test 99F007.

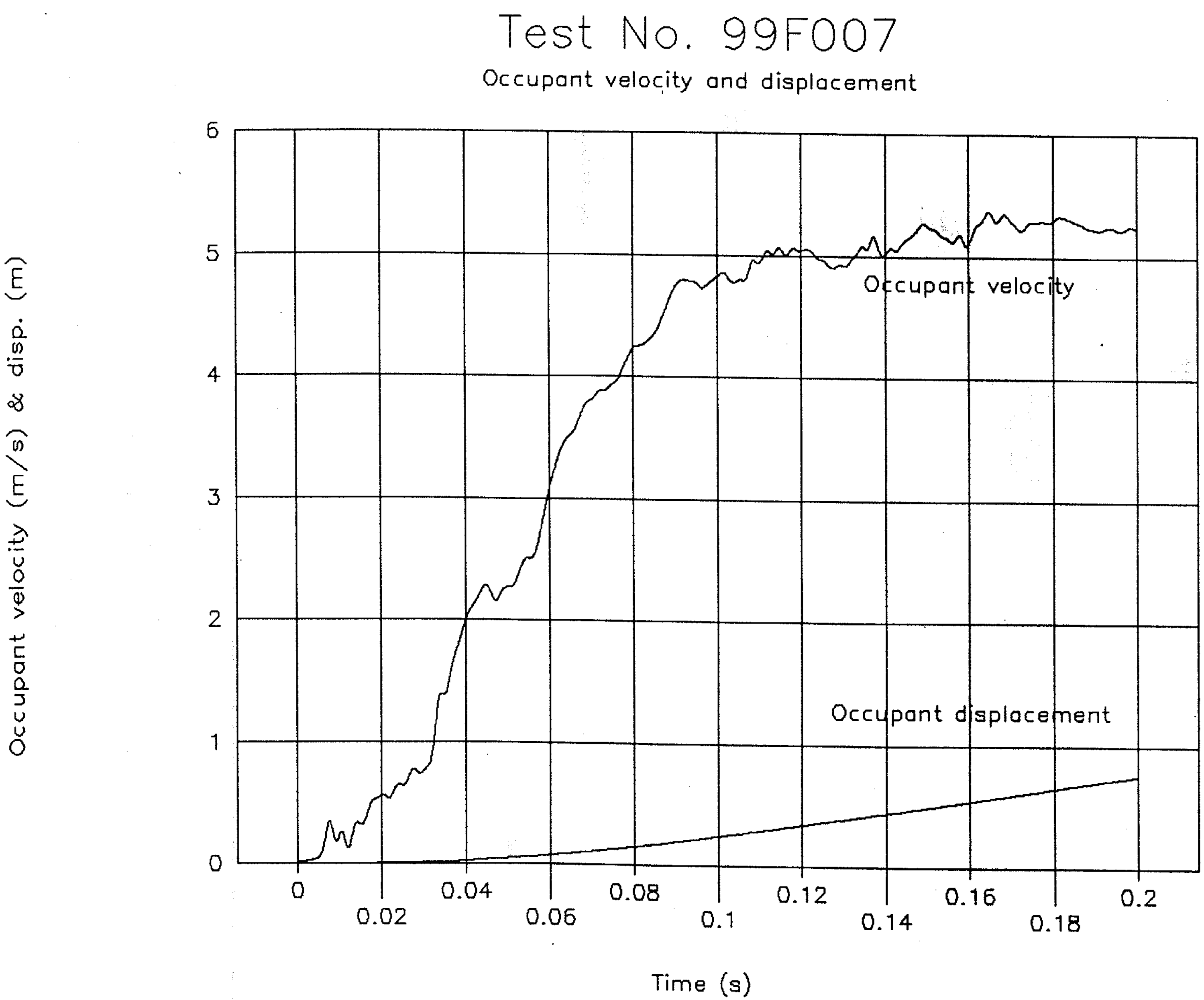


Figure 15. Longitudinal occupant velocity and displacement vs. time, test 99F007.

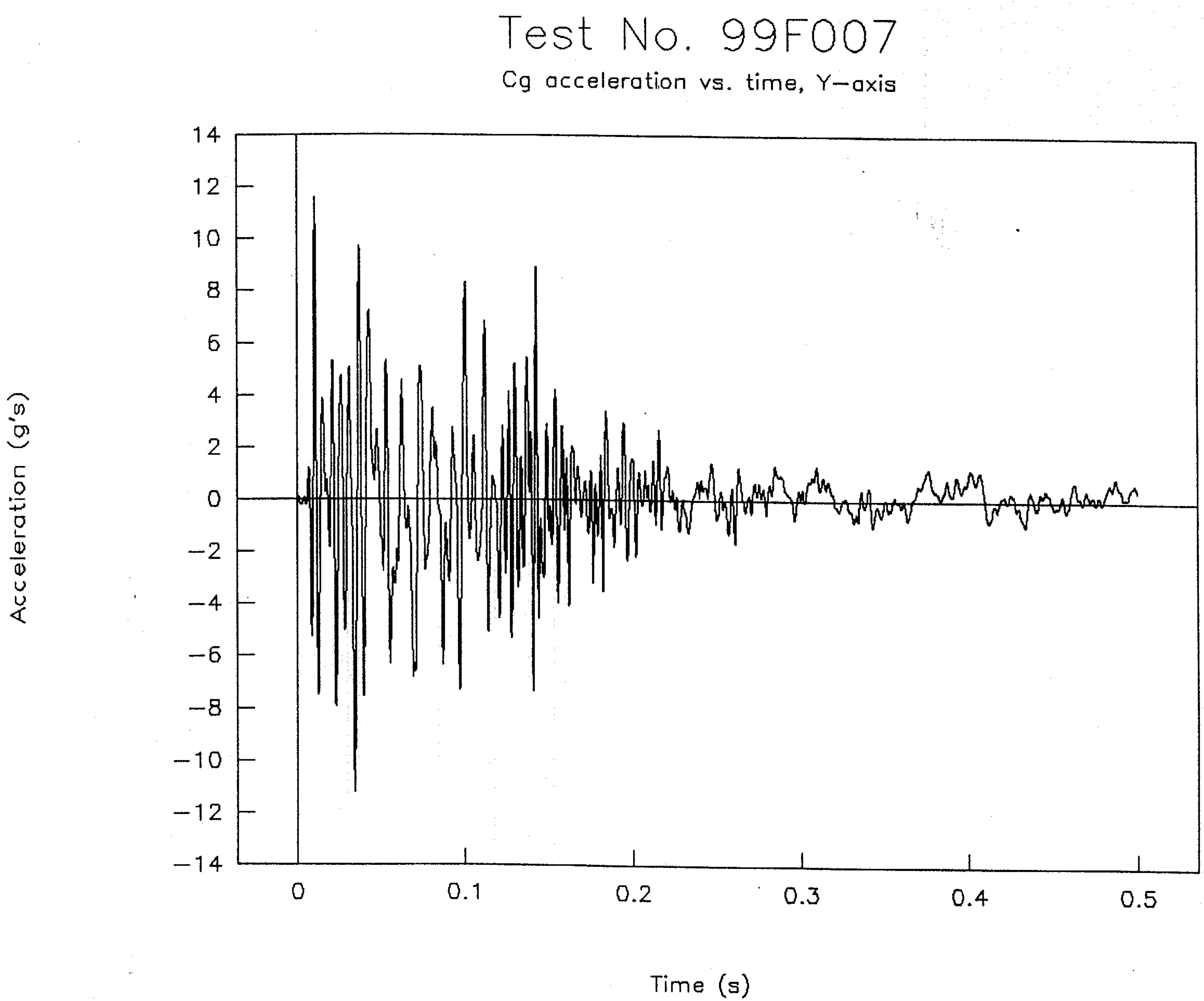


Figure 16. C.g. acceleration vs. time, Y-axis, test 99F007.

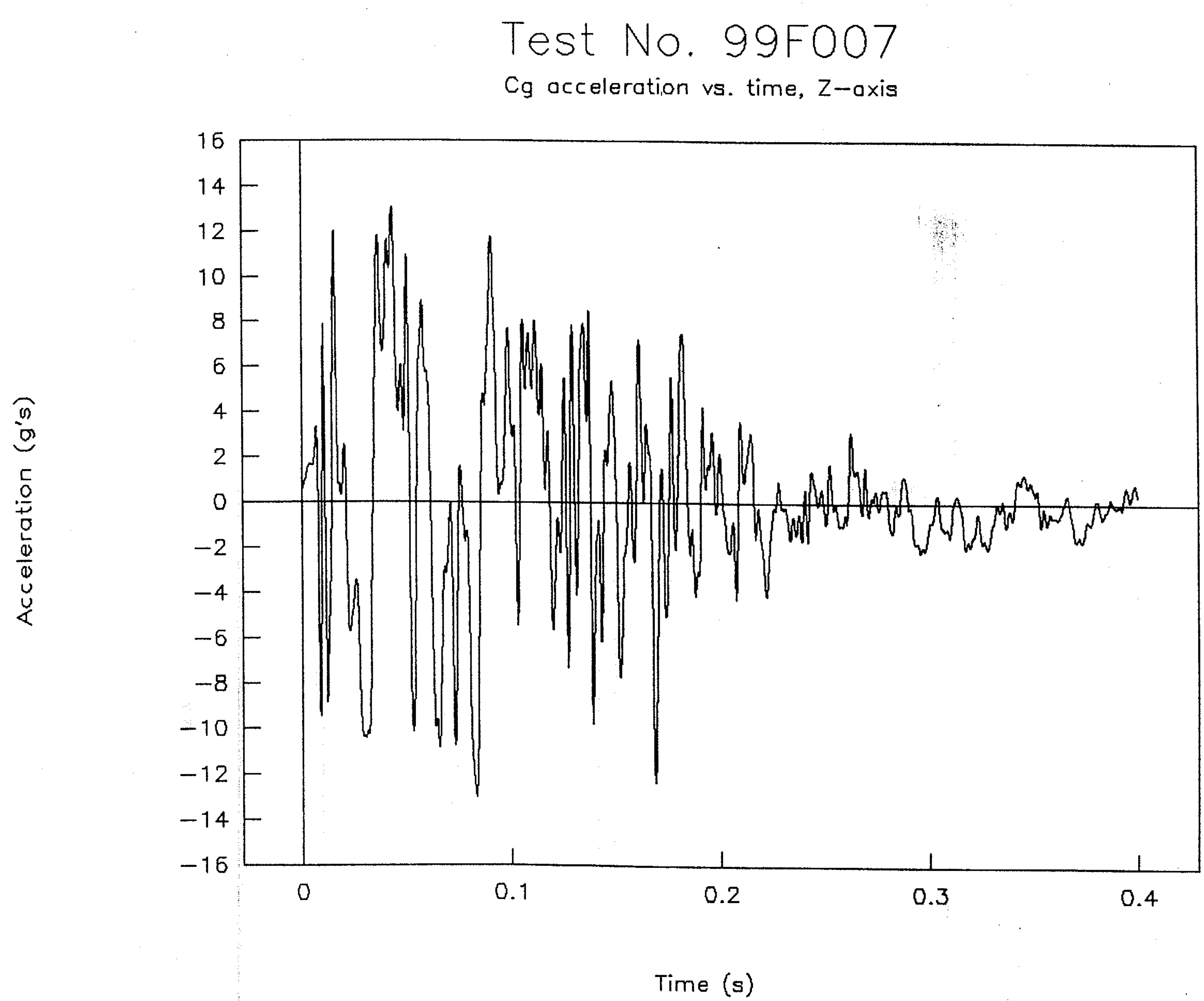


Figure 17. C.g. acceleration vs. time, Z-axis, test 99F007.

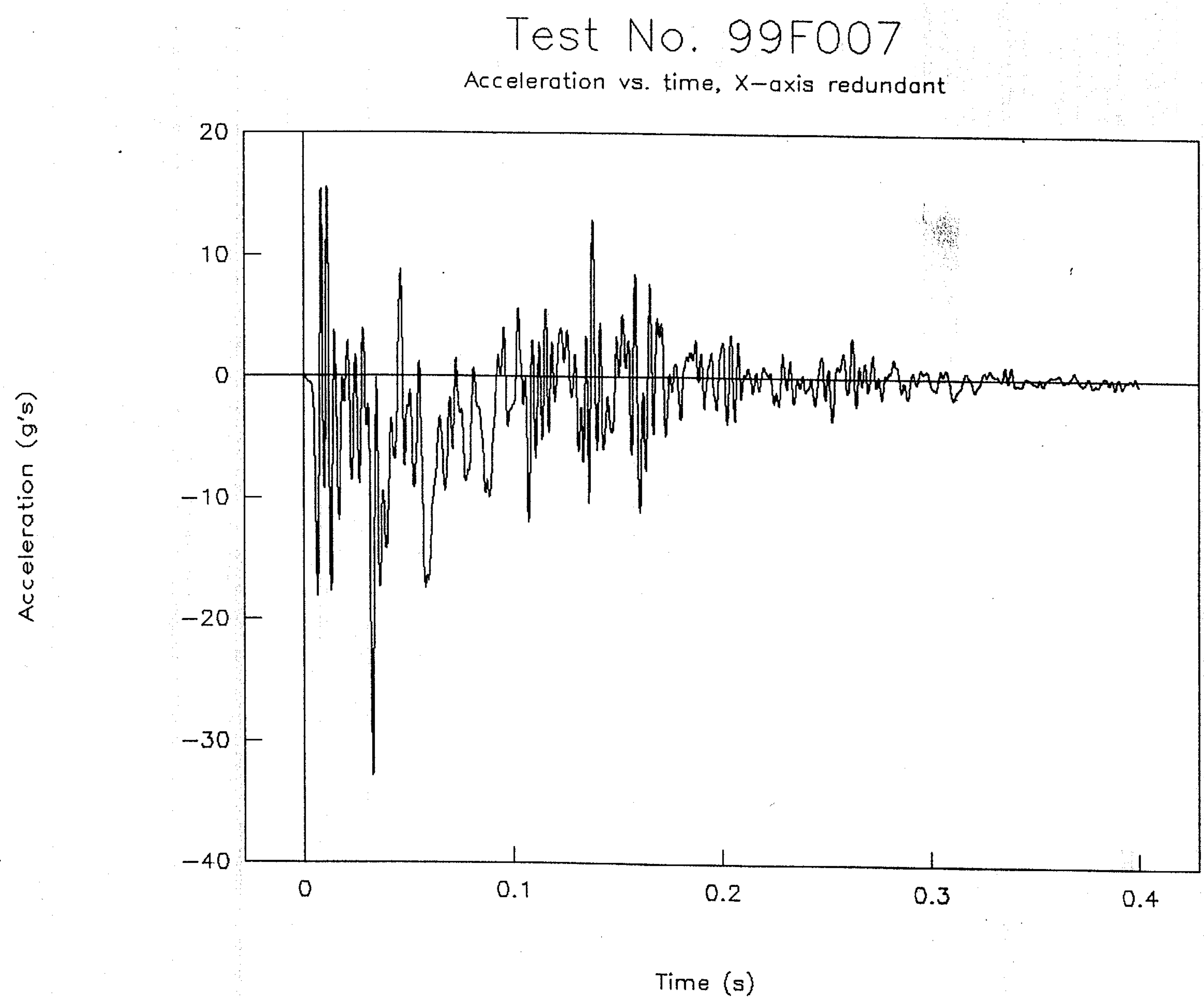


Figure 18. C.g. acceleration vs. time, X-axis redundant, test 99F007.

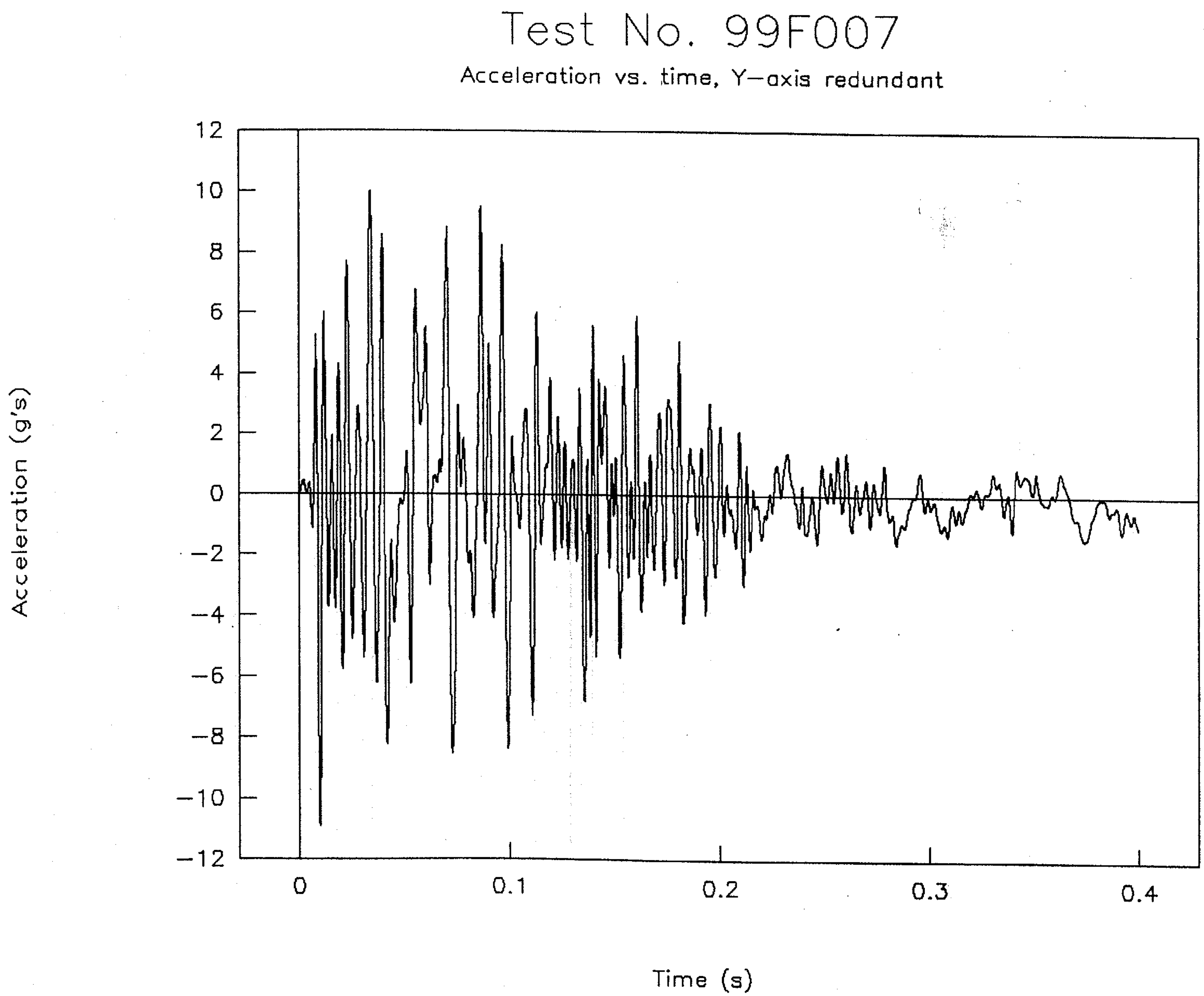


Figure 19. C.g. acceleration vs. time, Y-axis redundant, test 99F007.

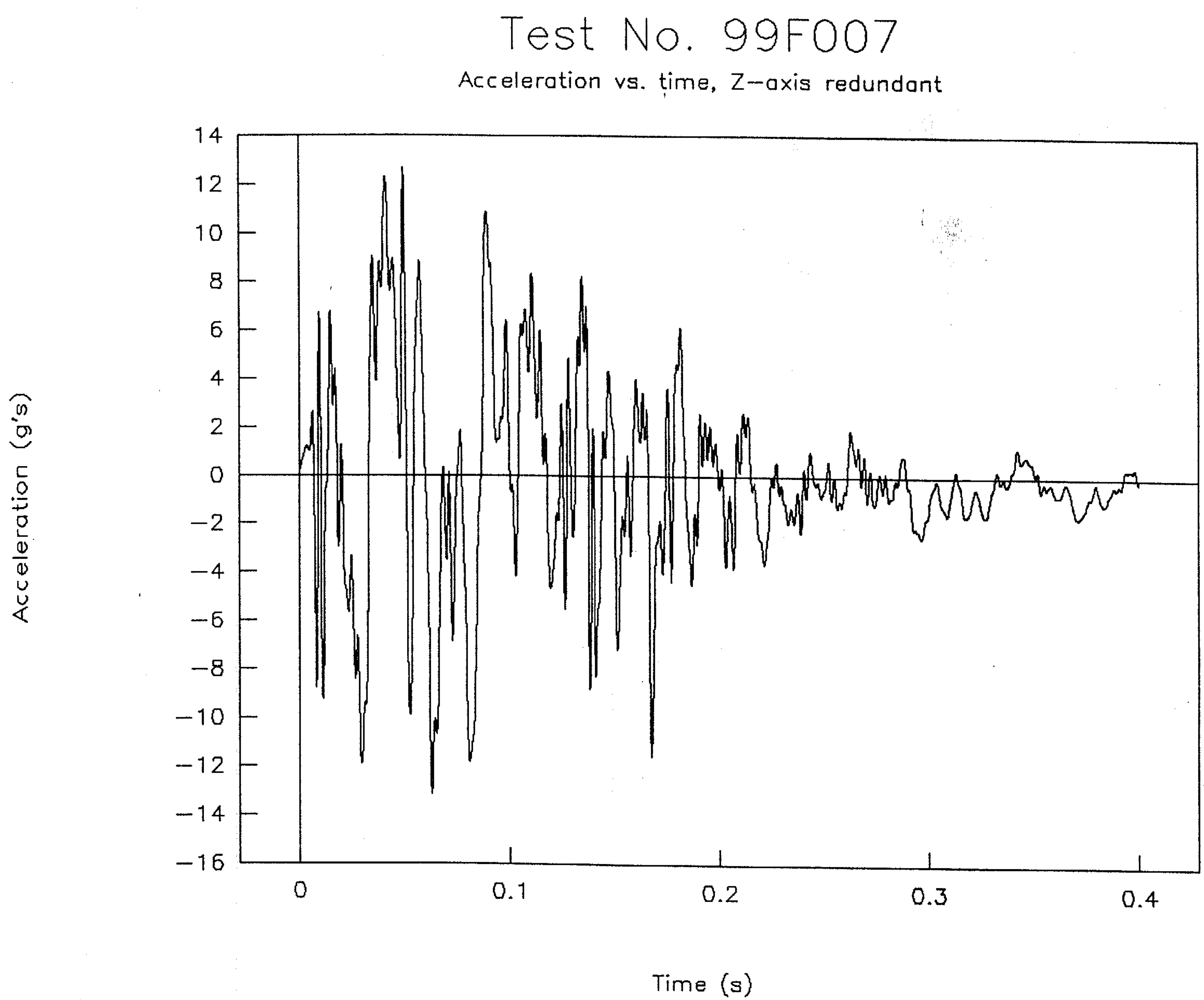


Figure 20. C.g. acceleration vs. time, Z-axis redundant, test 99F007.

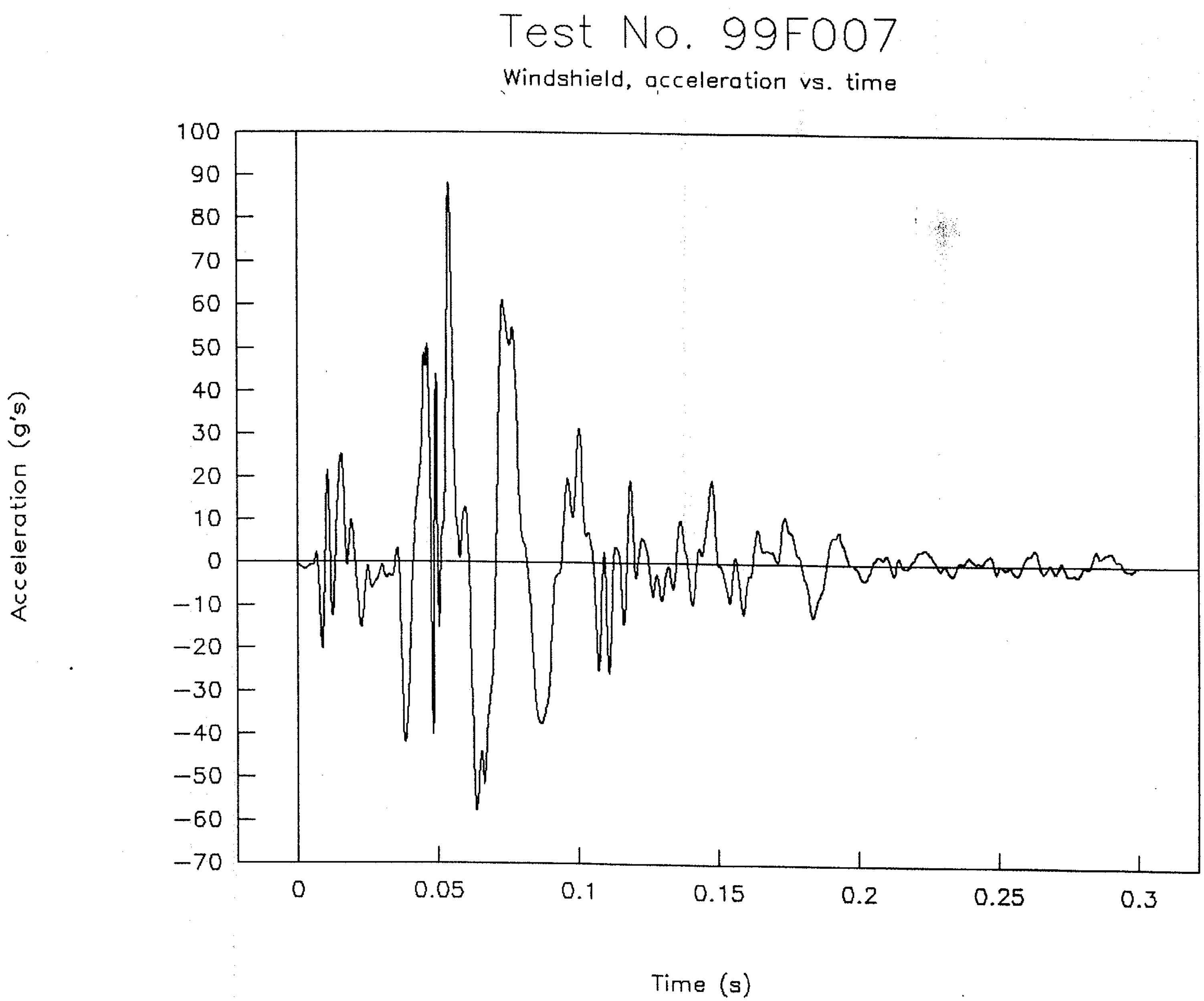


Figure 21. Windshield accelerometer, acceleration vs. time, test 99F007.

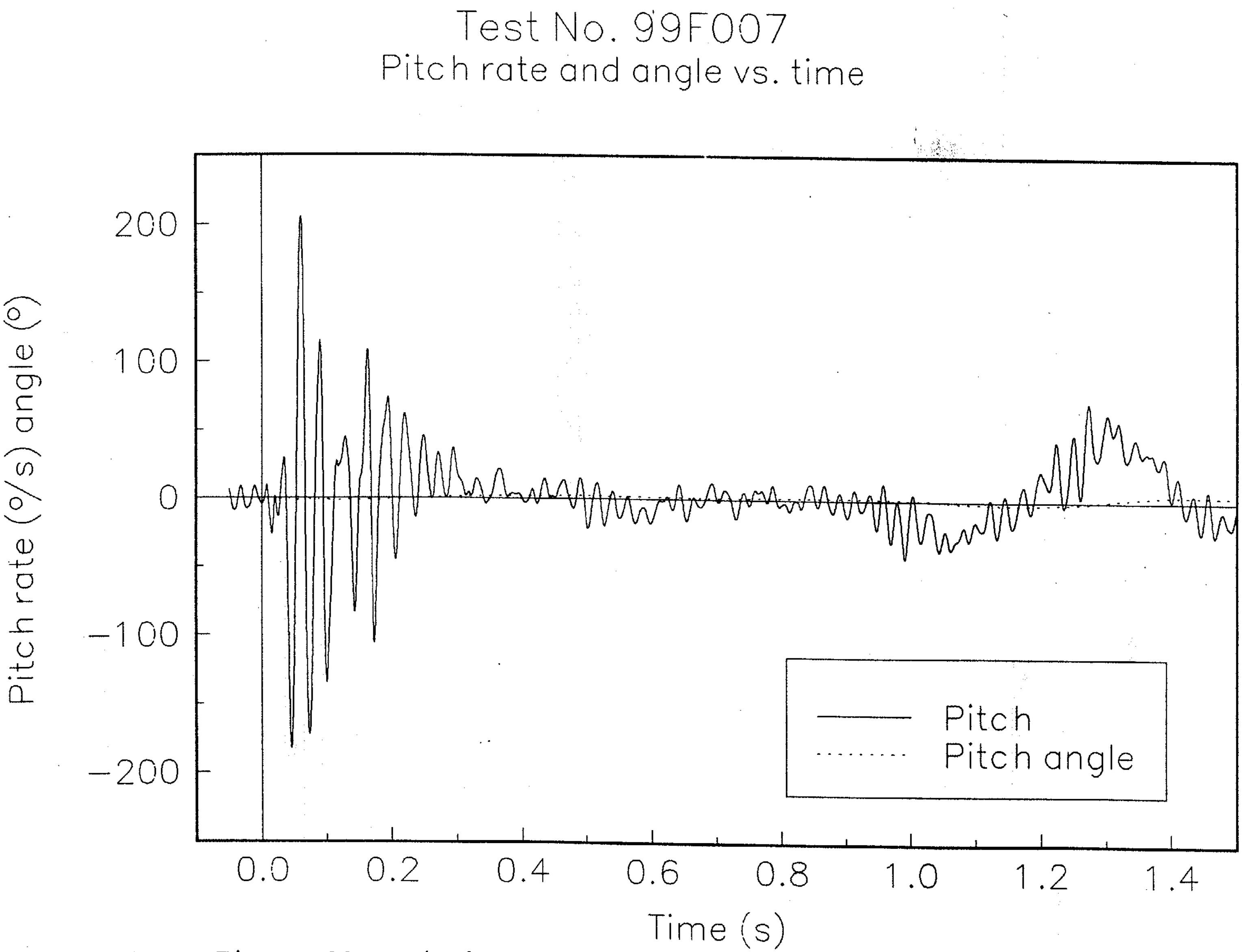


Figure 22. Pitch rate and angle vs. time, test 99F007.

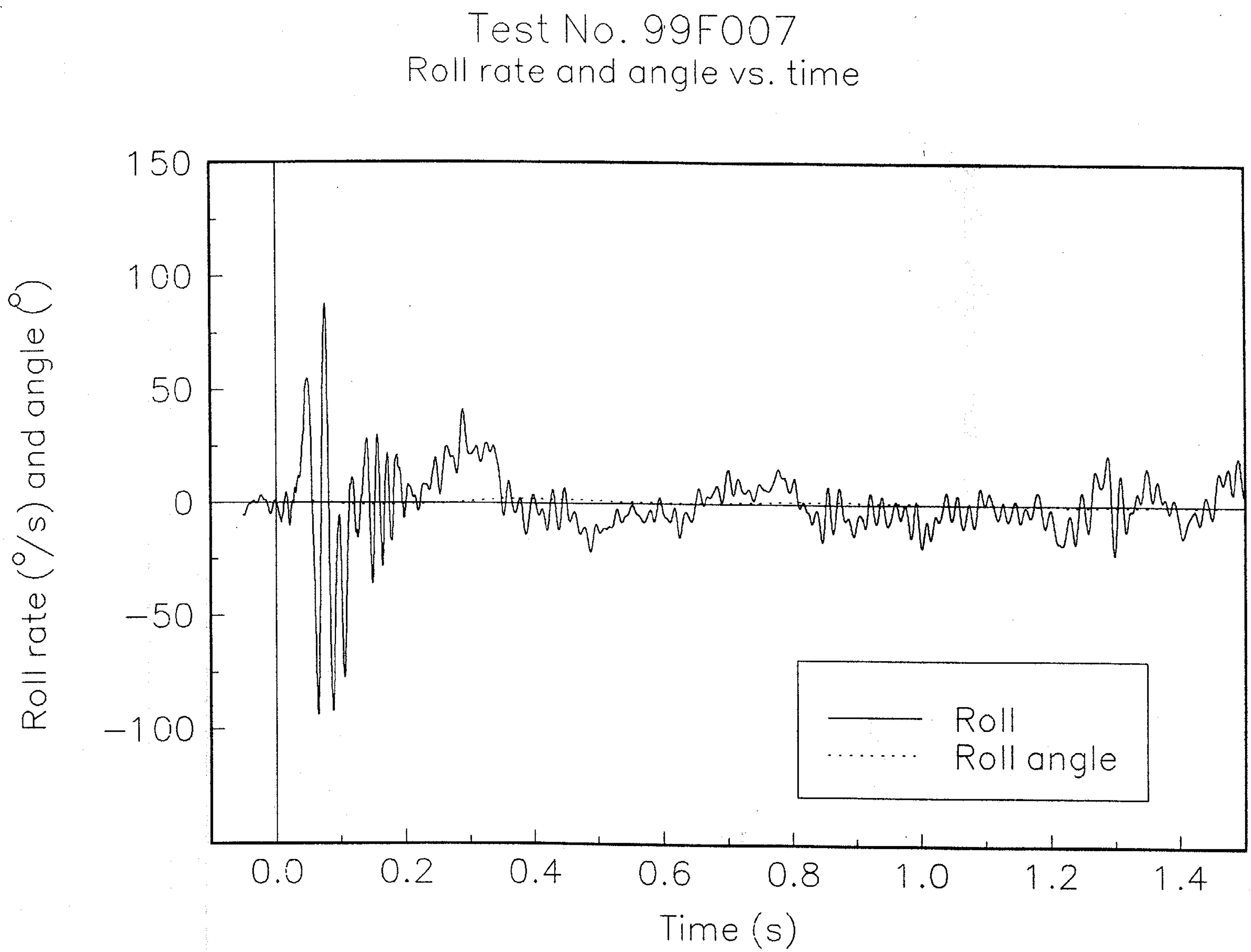


Figure 23. Roll rate and angle vs. time, test 99F007.

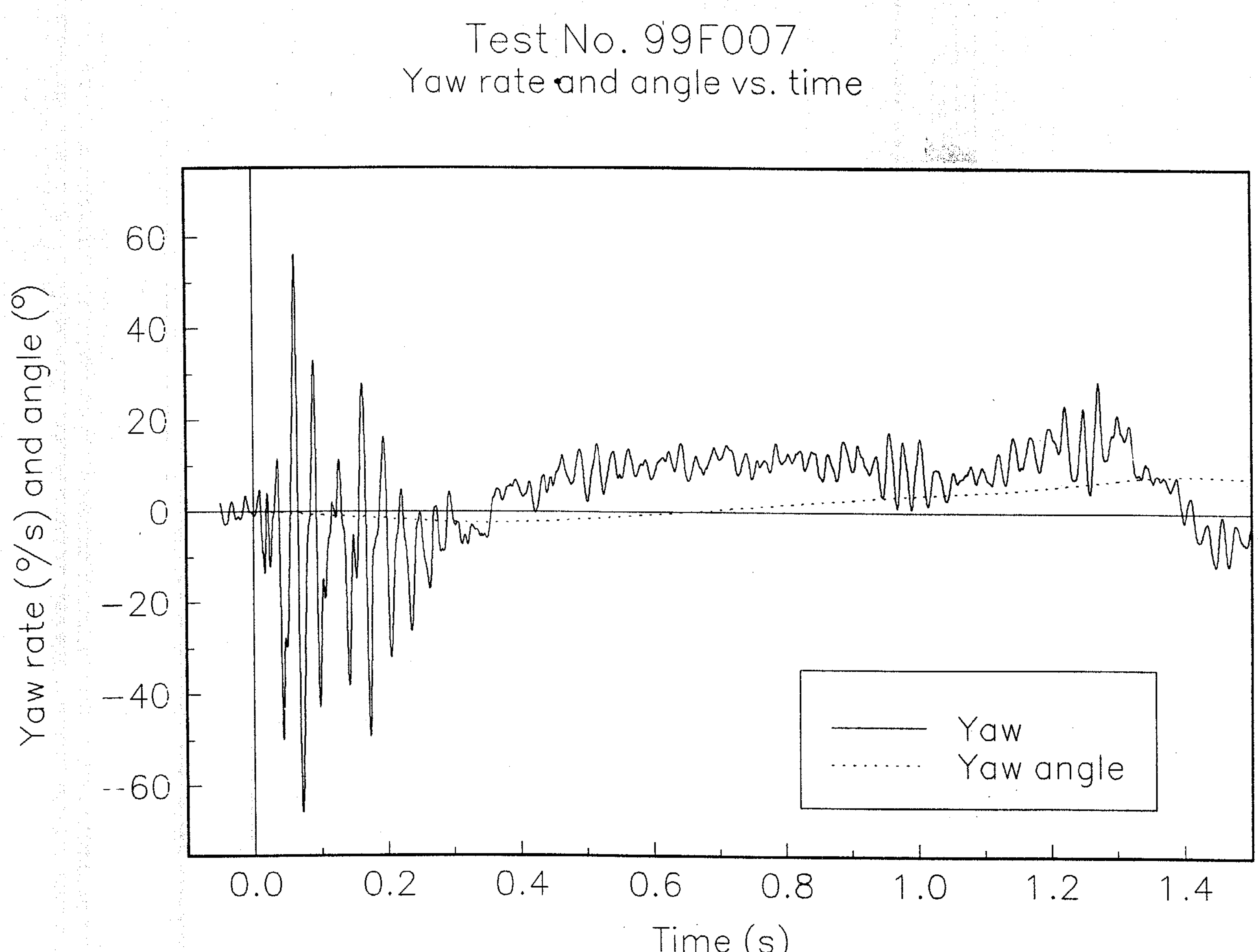


Figure 24. Yaw rate and angle vs. time, test 99F007.

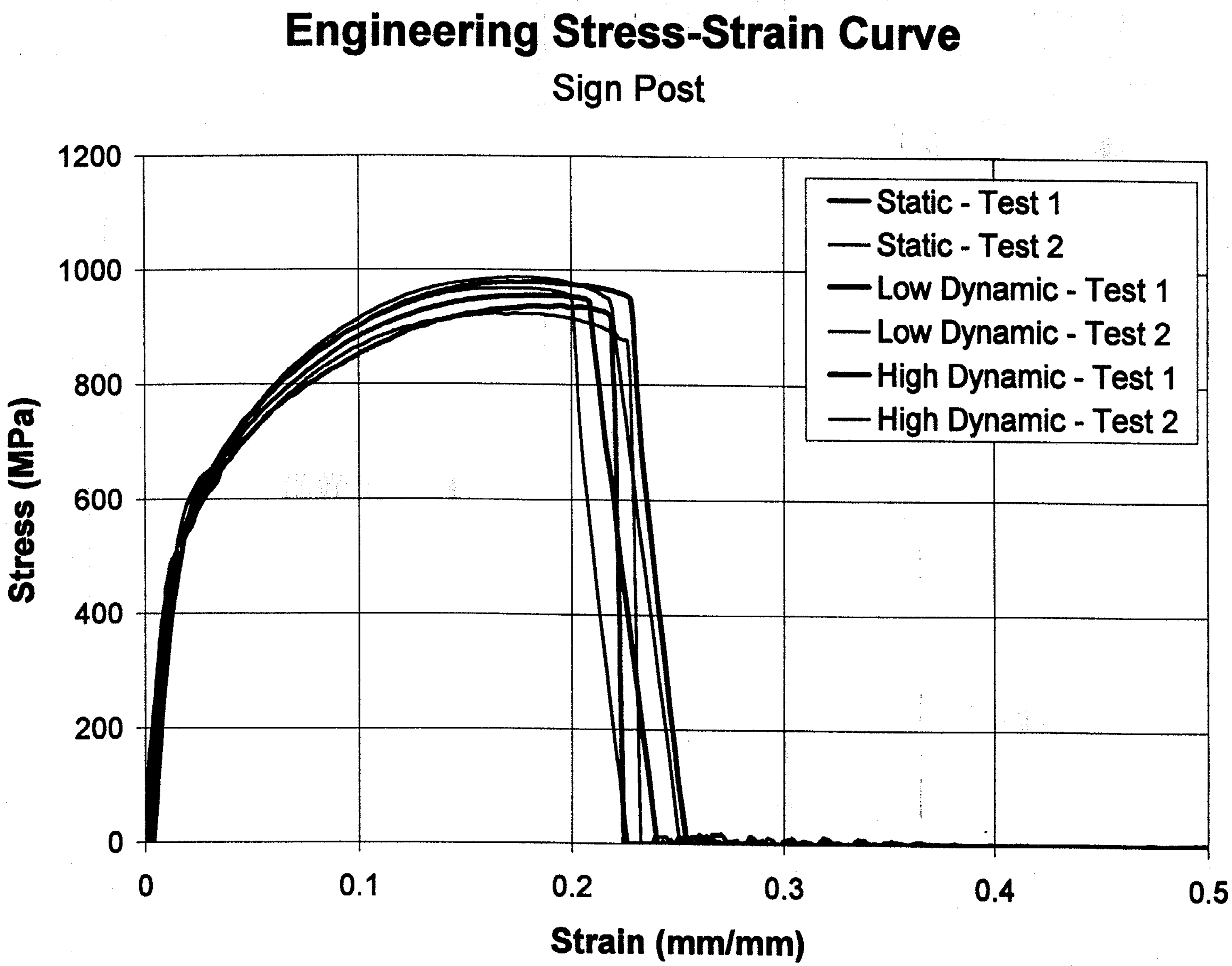


Figure 25. Engineering stress-strain curve for tested sign post, test 99F007.

REFERENCES

(1) Ross, H. E. Jr., Sicking, D. L., Zimmer, R. A., and Michie, J.D., *Recommended Procedures for the Safety Performance Evaluation of Highway Features, NCHRP Report 350,* National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 1993.